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ATMOSPHERIC WEATHERING TESTS ON ANODISED ALUMINIUM REFLECTORS

By W. E. HARPER, B.Sc., Ph.D., A.M.I.E.E. *(Member)*,* C. A. MORTON, B.Sc. A.M.I.E.E. *(Fellow)*,* and P. SMITH, A.R.I.C.**

Communication from the Research Laboratories of The General Electric Company Limited, Wembley, England.

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INTRODUCTION

We may expect developments in both the mechanical and optical design of lighting fittings to follow the recent developments in plastics and light metals, though it is unlikely that the older materials will be displaced. These new materials should be regarded as complementary to the old. They give to the engineer media having new properties and so open for him new technical possibilities.

One of the most important of the new materials for reflecting surfaces is electrolytically brightened and anodised aluminium.

Aluminium has a naturally high resistance to corrosion, due to the rapid formation of a thin, tightly adhering film of aluminium oxide over the surface when the metal is exposed to the air.

This corrosion resistance is increased when a thicker oxide film is built up by the electrolytic process known as "anodising." The work to be protected is made the anode in a suitable electrolyte, and a predetermined current passed under controlled conditions of temperature for a time determined by the thickness of anodic film required. Nascent oxygen is liberated at the anode and reacts directly with the metal to form the oxide film.

Although formed in aqueous solution and having a water content, the film is almost certainly amorphous Al_2O_3, and not a hydrate or hydroxide. When the film has reached the required thickness it is "sealed" by immersion in boiling water or other solution, part or all of the amorphous oxide being converted to the crystalline monohydrate.

The anodic film is not homogeneous. In addition to the water content it usually contains traces of the electrolyte, the actual quantity being variable and dependent on the method of production.

Production conditions also control the hardness of the film, which varies through a section perpendicular to the metal surface, the hardest portion

* Research Laboratories of the General Electric Company Ltd., Wembley, England.

** Alumilite and Alzac Ltd.

being that next to the metal. Hard films are brittle so that any deformation of the metal produces fine cracks in the film, but these close if the metal is bent back. The adhesion of the film is so good that it does not scale off even under repeated bending.

Aluminium reflectors are generally pretreated before anodising, either to increase the reflectivity of specular surfaces or to produce the required characteristics of a matt surface by etching and brightening.(1)

It is necessary that the relevant properties, such as the reflectivity, of any material which is to be used in lighting fitting construction should not seriously deteriorate over a period of 8-10 years, which may be regarded as a reasonable life of lighting equipment. None the less, it would be unreasonable to expect many materials to satisfy this demand in every type of atmosphere in which lighting fittings have to function; it is a part of the responsibility of the illuminating engineer to define the types of atmosphere and location in which a given material may be expected to satisfy his requirements.

In the present work the deterioration of the reflection characteristics of anodised aluminium surfaces when exposed for a period of 6-7 months in different atmospheres has been studied.

The investigation shared the difficulties and limitations common to all corrosion tests, and, in particular, the difficulty of complexity. All weathering and corrosion phenomena are very complicated and any corrosion "rate" is the resultant of a large number of physico-chemical actions, whose progress is determined by many variables associated with both the test material and the corrosive medium.(2)

This complexity had to be considered when a decision was made as to whether the material should be tested by laboratory methods or under field conditions. There are reasons to commend both forms of test. In the laboratory a fuller degree of control is possible than in field work, and it is also possible to accelerate the tests artificially. On the other hand it is difficult to argue from data obtained under laboratory conditions to service performance. A laboratory test can be accelerated by increasing the corrosive effect of one or more of the factors which result in the corrosion or weathering attack. For example, the concentration of one of the corrosive elements may be increased, or the humidity or temperature varied to obtain a greater rate of attack. Acceleration by such selective means will, however, almost certainly distort the total process and make it impossible to extend safely any conclusions to the service behaviour of the material.(3) These, and other considerations associated with practical requirements, led to the adoption of field tests for the present investigation.

Tests of this nature are best conducted on a statistical basis, but limitations in the supply of aluminium coupled with the need to investigate the performance at a large number of definite locations made this approach impossible in the present tests. These tests must, therefore, be regarded only as a survey of the ground with an attempt to predict probable boundaries of usefulness of the material to the illuminating engineer. Subsequent tests have been designed to supplement this present work by a more thorough exploration of selected aspects of the problem.

(1) ORGANISATION OF TESTS

(1.1) Test Stations

The general scope and layout of the tests were determined by four factors:—

(1) The primary object of the tests, which was to determine, as far as possible and as rapidly as possible, the types of atmo-

Table I
Details of Test Stations

TABLE I
Details of Test Stations

Type of Location		Test Station Number	Test Station Details	Chief Corrosive Agents
Outdoor	General Urban & Industrial	1	A well-exposed position on a factory estate at Wembley.	Atmospheric sulphur dioxide
		2	Factory roof in Oldbury, a heavily industrialised Midland town	" " "
		3	Triangular test site (at Croydon) enclosed by gas works, generating station and railway	" " "
		4	General dock area at Greenock	" " "
	Marine	5	First stage platform of the Tower, Blackpool	Chlorides from sea ; atmospheric sulphur dioxide
		6	Newquay, Cornwall ; batten carrying specimens mounted on cliffs, 50 ft. above sea-level	" " " " "
Indoor	Light Industrial	7	A railway goods depot with covered roof and open ends	Atmospheric sulphur dioxide
		8	A modern general machine shop with good ventilation	" " "
		9	A modern laundry in a rural area	" " "
		10	Cooker repair shop of seaside electrical supply company. Tinning and degreasing baths operating near batten.	Fumes from tinning and degreasing baths. Atmospheric sulphur dioxide
		*11	The window area of a shop in an industrial district	Atmospheric sulphur dioxide
		*12	General area of a shop in a seaside town	Atmospheric sulphur dioxide ; possibly chlorides from sea
	Heavy Industrial	13	Railway engine shed ; batten mounted 25 ft. above floor level	Sulphurous compounds, dirt and steam from locomotives
		14	Large steel rolling mill ; batten 40 ft. above floor level	Sulphur dioxide ; dirt
		15	Large iron foundry ; batten adjacent to cupolas	Sulphurous compounds, dirt, steam
		16	"Elektron" metal foundry producing incendiary bomb casings	Sulphurous compounds, dust
		17	Large tube mill ; batten mounted 15 ft. above hydrochloric acid pickling bath	Hydrochloric acid, sulphur dioxide, dirt
		18	Incoming end of island platform of main line railway station ; covered roof immediately above batten	Sulphurous compounds ; dirt, steam
	Special Industrial	19	Dipping shop of Yorkshire dye works	Fumes from dye baths ; steam
		20	Pump house of nitric acid plant	Nitric acid fumes
		21	A modern soap works	
		22	Ammonium chloride plant of large alkali works	Fumes of ammonium compounds
		23	Scheelite reduction plant in lamp factory	Ammonia ; hydrochloric acid ; steam

* Supplementary test stations ; exposure during second period of test only.

sphere in which anodised aluminium can be used satisfactorily as a reflector material.

(2) Knowledge of areas and locations where corrosion trouble in lighting fittings had been experienced.

(3) Facilities for installation and maintenance.

(4) Material and labour available.

Within the limits defined by these factors a scheme was developed in which the test stations were grouped in two main sections, these sections being then subdivided into types of location thought to be important and representative for the test purposes. This division gave the following general scheme:—

(1) Outdoor stations:—
  (i) General urban and industrial stations.
  (ii) Marine stations.

(2) Indoor stations:—
  (i) "Light industrial" stations.
  (ii) "Heavy industrial" stations.
  (iii) "Special industrial" stations.

This general scheme was developed in turn to give the full scheme shown in Table I. Short details of the test stations and of the chief corrosive agents at the stations are included in this table.

(1.2) Atmospheric Records

The difficulty of interpreting data derived from atmospheric weathering tests is largely due to difficulty in obtaining and recording in detail the relevant data about the atmosphere. Variations in the composition and state of the atmosphere have such an important effect on the rate of attack that some investigators have concluded that mean figures over the duration of the test for such factors as rainfall, temperature and humidity are of little value. ([4]). In his work on the corrosion of non-ferrous metals, Hudson ([5]) was concerned with outdoor test stations and by exposing his samples at meteorological stations was able to obtain comprehensive data. This was not possible in the present tests, as information was required regarding certain specific locations, including both indoor and outdoor sites. The atmospheric records have consequently been limited to those which could be obtained simply and which were thought to be major factors in determining the rate of attack.

General consideration of the nature of weathering suggested that the rate and type of any attack on the reflector surfaces would depend mainly upon a combination of four factors:—

(1) Type and concentration of corrosive agents in the atmosphere.
(2) Rainfall.
(3) Relative humidity.
(4) Type and degree of solid pollution.

When interpreting performance data of materials obtained from field tests with reference to the behaviour of similar materials in general service, it is necessary to relate the conditions recorded at the various stations with the average climatological conditions for the locations concerned. For outdoor work equipment must be designed and performance assessed relative to conditions occurring in the country as a whole.

The present investigation covered the two three-monthly periods May-July, 1943, and November, 1943-January, 1944, the total period of exposure being approximately 200 days. Records are given for the individual periods in addition to the mean for the whole period.

(1.2.1.) *Concentration of Atmospheric Corrosive Agents; Estimation of Sulphur Dioxide Concentration.*

There are gases present in every atmosphere, which, under suitable conditions, will attack most materials used in lighting equipment. The intensity of attack, however, varies greatly both with the type and con-

centration of corrosive agents present and with the material under test.

It is difficult to estimate the concentration of many atmospheric corrosive agents over a prolonged period, but fortunately a simple method has been devised by the D.S.I.R. for the measurement of the sulphur dioxide content, which is probably the most widespread and important agent from a corrosive point of view.

This method does not determine the absolute concentration of sulphur gases in the atmosphere, but records the average level of sulphur pollution over a considerable period of time. Lead peroxide is used as an absorbent, the atmospheric sulphur dioxide combining with it to form lead sulphate, which can be estimated readily at the end of the test period.

In the present tests a length of art tapestry cloth was wrapped round the centre portion of a 1¼ in. diameter glass tube 6 in. long. The cloth was stitched to form a tight sleeve and secured to the tube by a binding of adhesive tape at each end. The tape was bound so that the length of tapestry cloth left uncovered was 4 in. long, which gave an exposed area of cloth of approximately 100 sq. cm. The lead peroxide was prepared as paste, by mixing 8 gm. of analytically pure peroxide with 5 c.c. of a 1 per cent. gum tragacanth mucilage, and was worked evenly into the cloth surface. The tubes were dried and stored in a virtually sulphur-free atmosphere.

This estimation was made for the whole period of the test at all stations, each cylinder being exposed for one month and then replaced by a fresh tube. A few of the tubes were damaged in transit over the period of the test and two batches were destroyed by enemy action. This has disturbed the balance of the results, since the losses all occurred during the second period, but allowance has been made for this in the summary of the results which are given in Table II.

TABLE II

Sulphur Dioxide Content of Test Station Atmospheres.

Test Station Number	Relative SO_2 Content		Mean
	Period 1 (May–July 1943)	Period 2 (Nov. 1943 Jan. 1944)	
1	4.4	*18.0	9.5
2	13.5	*29.1	20.6
3	18.2	*20.6	19.3
4	8.4	* —	8.4
5	8.4	*25.4	15.9
6	3.9	*7.8	4.6
7	5.2	10.5	8.3
8	1.6	*2.7	2.2
9	1.5	1.0	1.2
10	1.1	*2.4	1.5
11	—	4.7	4.7
12	—	1.5	1.5
13	24.7	—	24.7
14	7.6	12.9	10.9
15	40.4	*36.8	39.3
16	9.8	15.6	13.0
17	18.2	20.0	19.2
18	17.3	28.6	21.9
19	3.7	* —	3.7
20	5.6	—	5.6*
21	5.6	*17.6	11.3
22	3.2	* —	3.2
23	3.1	6.8	5.3

* Record incomplete due to loss of tubes by enemy action.

The relative sulphur dioxide contents of the atmospheres for the two individual periods of exposure, in addition to the relative mean values, are listed. The outdoor test stations show well-graded values ranging from the clean atmosphere of Newquay to the heavily polluted atmospheres of Oldbury and Croydon. As might be expected the values recorded at the indoor sites are much more variable, but the two sets of results representing "light industrial" and "heavy industrial" locations group well individually and relatively. At the "special industrial" group of stations the rate of attack is generally complicated by the presence of other chemical agents. The values at nearly all of the stations show a marked rise for

the winter period of the test, being 1.5—2 times as great as the values for the corresponding stations during the summer period. The greater increases at stations 1, 5, and 21 may be due to fortuitous local conditions.

(1.2.2) *Rainfall*

Rainfall is probably the most variable of the ordinary climatic elements both in place and time ([6]). Its effect on the rate of weathering attack is further complicated by the fact that it may exercise control on the action in opposing ways. It may initiate and accelerate the attack by dissolving the corrosive media in the atmosphere and depositing them in solution on the test surfaces. But it may also retard attack that has commenced by washing the surfaces and removing both pollution deposits and corrosion products. Such considerations make it apparent that the effect of heavy rain will be quite different from that of a fine mist, whilst the frequency and duration of rainfall are other important factors.

It would be difficult to obtain, analyse, and correlate these factors, which should properly be included in the term "rainfall" if its effect on any weathering attack is to be truly assessed. In the present work records have been limited to the measurement of the total rainfall at the outdoor stations (Table III.). The "average" rainfall for adjacent areas of the country and for the same periods of the year are given for comparison. These "average" rainfall figures are for the recognised standard period of the thirty-five years 1881-1915. The data are given in terms of rainfall per thirty days, as this offers a convenient basis for comparison and overcomes the difficulty that the exposure periods at the different stations in the present tests were not precisely identical.

In the British Isles the maximum rainfall occurs in the north-west of the country, decreasing to a minimum in the south-east. The British Isles as a whole has an annual average rainfall of 41.4 in., or 3.4 in. per 30 days. While a small area of the country has an annual average of over 100 in. and another an annual average of less than 20 in., "practical" average maximum and minimum values may be taken as 80 in. and 25 in. respectively, or 6.6 in. per 30 days and 2.0 in. per 30 days([6]). On this basis the conditions during the test at the different stations covered the average

TABLE III

Rainfall at Outdoor Test Stations—Inches per 30 Days.

Test Station	Present Test Period 1 May-July 1943	"Average" Fall May-July	Present Test Period 2 Nov. 1943-Jan. 1944	"Average" Fall Nov.-July	Mean	
					Present Test	"Average" Fall
	ins.	ins.	ins.	ins.	ins.	ins.
1. Wembley	1.5	2.0 (Kew)	1.6	2.1 (Kew)	1.5	2.0 (Kew)
2. Oldbury	1.9	2.3 (B'ham)	1.6	2.4 (B'ham)	1.7	2.3 (B'ham)
3. Croydon	1.3	2.0 (Kew)	1.6	2.1 (Kew)	1.4	2.0 (Kew)
4. Greenock	4.3	2.7 (Glasgow)	5.7	3.7 (Glasgow)	5.0	3.2 (Glasgow)
5. Blackpool	3.5	3.3 (Stony-hurst)	2.9	4.4 (Stony-hurst)	3.2	3.8 (Stony-hurst)
6. Newquay	2.1	2.4 (Fal-mouth)	3.2	5.1 (Fal-mouth)	2.6	3.7 (Fal-mouth)

range satisfactorily, though on the whole the rainfall was below the average for both periods of the test.

(1.2.3) *Humidity*

The relative humidity of the atmosphere may be another important factor in determining the rate of weathering attack. Hudson(7), in discussing the corrosion of iron and steel, suggests that the atmospheric humidity, if above a certain value, and the atmospheric pollution are the two factors controlling rusting. Many of the solids which deposit on metals and most of the corrosion products have the property of absorbing moisture at humidities less than 100 per cent. The rate of corrosion increases rapidly at some humidity which is probably related to this moisture absorption, though this critical humidity will vary with the absorbent material. Vernon(8), in some laboratory tests on iron and steel, showed that in air with a relative humidity less than approximately 70 per cent., very little rusting occurs, whether the atmosphere is polluted or not. In atmospheres contaminated with sulphur dioxide there is a pronounced increase in the rate of rusting when the relative humidity rises above 80 per cent. It is possible that a similar process will occur during the exposure of anodised aluminium to the atmosphere.

Moreover, moisture films may form over reflector surfaces—particularly in outdoor locations—quite apart from their wetting by rain. It has been stated that a surface film of moisture is always present on such surfaces even in dry weather. In addition, films are produced as a result of temperature differences between the surface and the surrounding air, and also in mist or fog(9).

During the present tests relative humidity measurements were made at four stations, wet and dry bulb thermometers being used for the measurements. At Test Station 1 readings were taken at 0700 hours, 1100 hours, and 1500 hours G.M.T. throughout the test. Readings at the three indoor stations 8, 9, and 23 were taken once a day during the first period of the test. The data are presented (Table IV.) as percentage occurrence of relative humidities:—

(1) Higher than 80 per cent.
(2) Between 70 per cent. and 80 per cent.
(3) Below 70 per cent.

Mean relative humidity figures averaged over the whole year for different meteorological stations suggest that this quantity does not vary greatly over the country and has a value of approximately 80 per cent. Seasonal and diurnal variations in relative humidity, however, are considerable.

The values given for Station 23 are rather deceptive. Though usually the atmosphere was very dry, it became heavily laden with moisture during certain of the manufacturing processes and condensation occurred on

TABLE IV

Relative Humidity Data for Four Test Stations

Test Station Number	Time	Period 1 (May-July, 1943)			Period 2 (Nov., 1943-Jan., 1944)		
		> 80%	70%–80%	< 70%	> 80%	70%–80%	< 70%
	hrs.						
1	0700	29%	39%	32%	66%	25%	9%
	1100	8%	9%	83%	42%	27%	31%
	1500	11%	16%	73%	30%	30%	40%
	Mean	16%	21%	63%	46%	27%	27%
8	Mean	10%	10%	80%	—	—	—
9	Mean	4%	10%	86%	—	—	—
23	Mean	3%	3%	94%	—	—	—

the specimens, emphasising again the difficulty of adequately recording moisture data.

(1.2.4) *Solid Pollution*

The presence of solid particles in the atmosphere relative to weathering attack on a surface is important for two reasons:—

(1) Their presence will affect the *type* of attack which may take place. In a clean atmosphere we may expect the surface to be attacked more or less uniformly, but where solid particles are deposited on the surface they will probably act as "centres" of attack, resulting in a selective localising of the action.

(2) Deposited solids may absorb and retain moisture which is carrying dissolved corrosive media, so increasing the degree of attack in the immediate area of the deposited particles beyond the general attack which would occur in pollution-free atmospheres.

Three types of particle have been distinguished as generally present in the atmosphere(9):—

(1) Heavy inorganic particles derived from smoke, fumes, and dust, and varying in diameter from .001-100μ.

(2) Organic material such as bacteria, plant spores, and pollen;

(3) Water vapour particles — fog, mist, and rain. These particles have been considered in the preceding sections.

The type and rate of deposition of particles is due to a combination of gravitational and aerodynamic forces, including convection currents where heat, as from a lamp, is present.

Experiments have shown that the amount of solid deposited on a surface increases tenfold when the surface is wetted, so that we might expect a preferential increase in local attack as the frequency of wetting increases.

An attempt was made to assess the solid pollution at the different outdoor stations from an analysis of the collected rainwater, but, due to loss of samples by transport and other causes, the data were not sufficiently comprehensive to be representative of conditions over the whole period of the test.

(1.3) Details of Specimens

(1.3.1) *Optical Properties of Anodised Aluminium Reflecting Surfaces*

The reflectivities of specularly reflecting anodised aluminium surfaces vary with the purity of the metal, with variations in processing and with the thickness of the anodic film.

It is convenient to recognise three qualities of aluminium for use as reflector surfaces:—

(1) Grade A—99.99 per cent. purity aluminium;

(2) Grade B—99.8 per cent. purity aluminium;

(3) Grade C—Good quality commercial aluminium.

(Grade C metal is not usually used for specular reflectors.)

In general terms, for the same film thickness the specular reflectivity decreases sharply as the purity decreases,(10) the diffuse reflectivity increasing correspondingly; the total reflection factor remains substantially constant. Measurements made on test samples having an anodic film thickness of approximately 0.0001 in. gave the following mean values of specular reflectivity before exposure:—

Grade A metal—83 per cent.;
Grade B metal—79 per cent.

Measurements made on similar samples prepared subsequently gave rather lower results, namely:—

Grade A metal—82 per cent.;
Grade B metal—76 per cent.

This suggests that there may be a measurable variation in the specular reflectivity of apparently identical samples prepared at different times,

due probably to variation in the metal. Such variations are less marked in Grade A material than in the lower-grade metals.

The effect of increasing film thicknesses on the specular and diffuse reflectivities (as defined in Sections 1.4.2 and 1.4.3) of Grade A and Grade B metals, which were electrolytically brightened before anodising, is shown

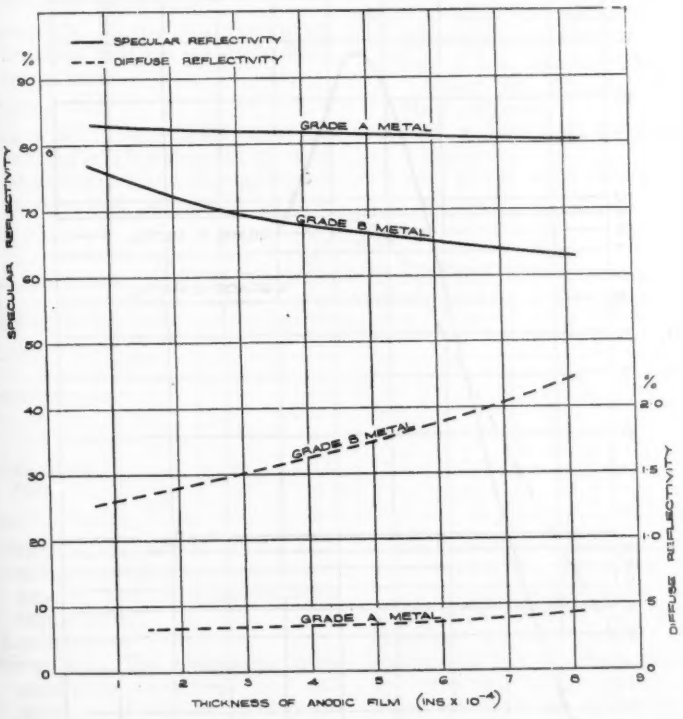


Fig. 1. Relation between thickness of anodic film and (1) specular reflectivity and (2) diffuse reflectivity of typical specular samples of grade A and grade B anodised aluminium.

in Fig. 1. The exaggerated effect shown by the Grade B metal may be due to the inclusion in the anodic film of impurities contained in the metal resulting in a more cloudy film.

A wide range of matt finishes can be produced by different etching treatments, and this flexibility in surface finish offers considerable possibilities for reflector design. It will be necessary, however, for the processes to be closely controlled so that any given finish can be accurately reproduced. Two finishes were chosen for test specimens, one on Grade B metal and one on Grade C metal. The corresponding curves of brightness distribution are given in Figure 2 for light incident at 45 degs. to the normal to the specimen.

(1.3.2) *Preparation of Specimens*

Both reflectors and flats were included in the test equipment of the

stations, and summaries of the pretreatment, anodising and sealing processes used in their preparation are detailed below and in Table V.

(1) Degreasing and Washing:—

Process D.1: The specimens were immersed for a few minutes in a boiling aqueous solution of

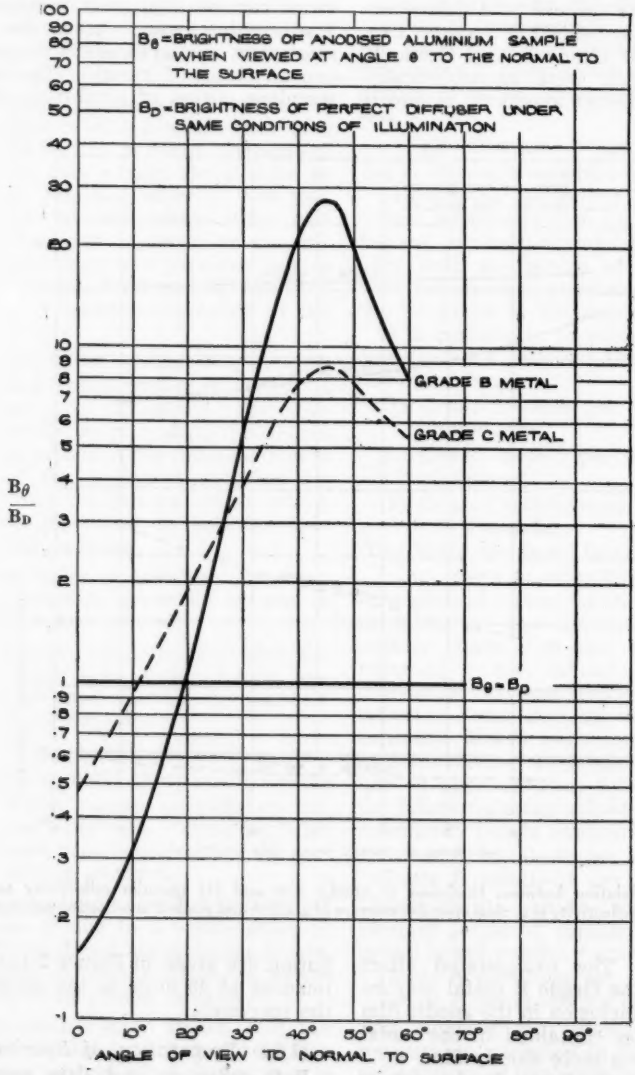


Fig. 2. Brightness distribution given by typical matt samples of grade B and grade C anodised aluminium with light incident at 45° to the normal to the surface.

sodium triphosphate, sodium metasilicate, and a wetting agent until the metal was visibly free from grease.

Process D.2: Immersion for 10-15 secs. in boiling 5 per cent. caustic soda.

(2) Electrolytic Brightening:—

Process B.1: The metal was treated at the anode in an air agitated hot acid electrolyte.

Process B.2: Anodic treatment in an aqueous solution of hydrofluoboric acid.

(3) Etching:—

Process E.1: The metal was immersed in a hot aqueous solution of sodium hydroxide, copper sulphate and ammonium hydroxide, the depth of the etch being controlled by variations in time of immersion and solution temperature.

(4) Anodising:—

Process A.1: The specimens were anodically oxidised in sulphuric acid solution at 68 degs.-70 degs. C. and at 16 volts. The thickness of the anodic film was controlled by time of treatment.

(5) Sealing:—

Process S.2: Specimens were immersed in water at 100 degs. C., the pH value being adjusted to 5.8 by addition of phosphoric acid and chromic acid.

The film thickness used on the BS and CS series of samples was chosen to give the maximum specular reflectivity with minimum corrosion resistance and so provide a datum of reference. The thicker coatings on the AS series and on the reflectors enabled the value of thicker films to be judged relative to service performance.

(1.3.3) *Equipment of Test Stations*

The following specimens were exposed at each test station:—

1 Specular reflector;
1 2-in. x 2-in. Specular flat of each series (AS, BS, and CS);
1 Matt reflector;
1 2-in. x 2-in. Matt flat of the CM series;
2 2-in. x 2-in. Matt flats of the DM series.

TABLE V

Processes used in preparation of test specimens

Type of Specimen	Series Designation	Grade of Aluminium	Degreasing Process	Brightening Process	Etching Process	Anodising Process	Sealing Process	Film Thickness
								in.
Specular Reflectors	—	A	D.2	B.1	—	A.1	S.2	.0003
„ Flats	AS	A	„	„	—	„	„	.0003
„ „	BS	A	„	„	—	„	„	.00008
„ „	CS	B	„	„	—	„	„	.00008
Matt Reflectors	—	B	D.1	B.2	E.1	„	„	.0003
„ Flats	CM	B	„	„	„	„	„	.0002
„ „	DM	C	„	„	„	„	„	.0002

The flats and the lead peroxide tube were mounted on the underface of a wood batten, the face being cut at an angle of 30 deg. to the horizontal. Bakelite washers were used as spacers to lift the flats about ¼ in. from the face of the batten, the flats being secured by cadmium plated steel wood screws bearing directly on the surface of the specimens. The lead peroxide tube was held in Terry spring clips in the centre of the batten and mechanically protected by a perforated galvanised housing. The two reflectors hung vertically from wooden blocks at the ends of the batten, and were secured by the shade rings of cadmium plated lampholders which carried the lamps or

heaters. Fig. 3 shows a complete batten photographed from below before exposure. At the outdoor stations the battens were mounted so that the exposed surfaces of the flats faced south.

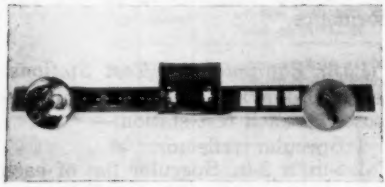


Fig. 3. Batten with specimens.

Under service conditions most reflectors operate at raised temperatures when the lamps are on, and the test reflectors were operated at raised temperatures. Temperature rises of approximately 60 deg. C. above ambient temperature were obtained by using 230 V. 100 W. lamps in the indoor locations and 230 V. 200 W. tubular heaters outdoors. Heaters and lamps were burned continuously except at three indoor sites where special conditions required operation during factory hours only. Two reflectors of each type were available for installation at Station 1. Only one pair was fitted with heaters, so that the effect of heating on the progress of weathering at this station could be studied.

(1.4) Methods of Measurement

It is important that two characteristics of the reflecting surface of a lighting fitting should not change greatly during its service life. These are:—

(1) The appearance of the surface;
(2) The optical performance of the fitting.

While the maintenance of performance is the first consideration, it is usually linked with the appearance of the surface and both factors have been studied.

(1.4.1) *Assessment of Appearance*

In addition to a general visual and microscopic examination, photographs of the specular flats when lighted directionally were taken under controlled conditions at the end of both periods of the test.

A number of attempts has been made to assess quantitatively different aspects of the appearance of polished metals. Champion ([11]) has described a useful scheme for recording the extent of pitting, and this was used in the present work, though it was limited to recording the "density" or frequency of pitting in terms of the reference charts given by Champion.

Quantitative assessment of the degree of bloom or matting on a specular surface is more difficult. The method adopted was based on that developed by Kenworthy and Waldram ([12]). It uses the diffuse reflectivity at defined angles of incidence and view (45 degs. and 0 deg., respectively, in the present work) as a measure of the bloom. As a link between the actual appearance of samples and their diffuse reflectivities it is proposed that samples be regarded as having satisfactory appearances if their diffuse reflectivities measured under the given conditions are not greater than:—

(1) 2 per cent. for Grade A metal;
(2) 4 per cent. for Grade B metal.

The practical details of the measurement are described in the following section.

The effect of bloom on the appearance of a matt surface is not as important as it is for specular materials, and no attempt was made to estimate it beyond recording any changes that were apparent to the eye. Pitting will mar the appearance, however, and the degree of pitting of the matt flats was recorded.

It would be difficult to assess quantitatively changes in the appearance of reflectors, and records were limited to visual inspection data and photographs taken under standard conditions.

(1.4.2) *Assessment of Performance*

The performance of the specular flats during exposure was assessed by changes in their specular reflectivities, measurements being made at the end of both periods of exposure.

The layout of the apparatus is shown in Fig. 4. A portable photometer (P) was mounted on an arm which could be rotated about the specimen mount (S). This enables the photometer to view either directly or by reflection an opal window of uniform brightness in the box A; the interior of the box was painted matt white and was illuminated by a 40V. 20W. pearl lamp operated at 38V.

With the photometer in position 1, the brightness of the opal window was measured directly (B_1). The specimen was then inserted in the mount at 45 degs. to the incident light, the photometer rotated to position 2, and the brightness of the box as seen by reflection measured (B_2). Then—

specular reflectivity of specimen

$$= \frac{B_2}{B_1} \times 100 \text{ per cent.}$$

To obtain the diffuse reflectivity for the assessment of appearance under the conditions defined in the previous section the opal window was removed from the box A so that the specimen was illuminated by the direct light from the lamp. The photometer was rotated to position 3, and the brightness of the specimen in this direction measured (B_3). The specimen was then replaced by a matt opal test plate of reflection factor 80 per cent. and the brightness of this measured under the same conditions of illumination (B_4). Then—

diffuse reflectivity of specimen

$$= \frac{B_3}{B_4} \times 80 \text{ per cent.}$$

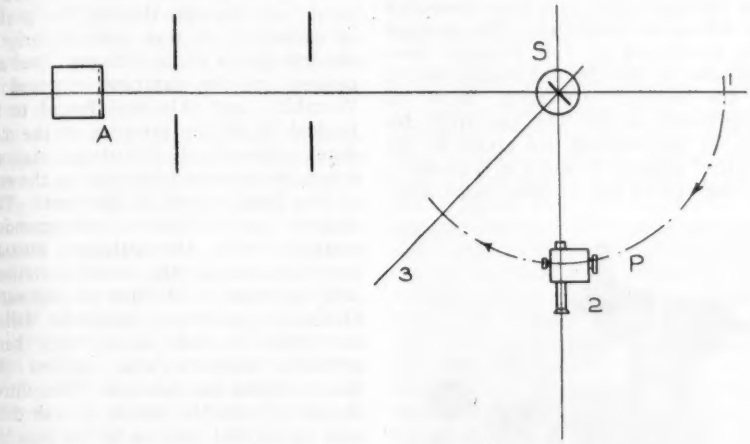


Fig. 4. Layout of apparatus for measurement of reflectivity.

The characteristics of preferentially reflecting surfaces are complex, and it was necessary to decide which properties of the surface were of first importance before deciding suitable performance tests for the matt flats. Surfaces similar in texture to the test samples are used for controlling light flux, so that their most important property is that corresponding to the specular reflectivity of specular surfaces. We may call this property their "specific reflectivity" and define it as the ratio of the brightness of the test

surface under given conditions of illumination and view to the brightness of a perfect diffuser under the same conditions. Angles of incidence and view of 45 deg. were adopted for this work, and measurements were made in a similar way to that described for the measurement of specular reflectivity.

Another surface property of matt reflectors which is of some importance, is the total reflection factor of the surfaces, and this was measured for diffuse incident light. The method was developed by J. S. Preston from one used by him for the measurement of the absolute reflection factor of magnesium oxide. The practical details of the method are given in the original paper([13]), and Fig. 5 shows a photograph of the modified apparatus.

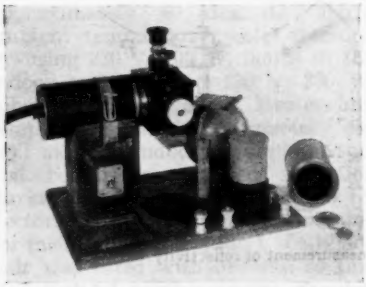


Fig. 5. Apparatus for measurement of total reflection factor of matt specimens.

The performance of the reflectors was determined by measuring the polar curves of light distribution before and after exposure, the reflectors being fitted with a 25 W. pearl G.S. lamp.

Both types of reflector were very uniform in appearance and performance before exposure, and initial mean polar curves were derived from measurements made on six reflectors of each type.

The specimens were inspected and cleaned at approximately monthly intervals during the period of exposure and carefully cleaned before any measurements were made. This maintenance was important relative to their appearance and performance and a standard cleaning procedure of washing with soap and water followed by light polishing was adopted.

(2) RESULTS OF TESTS

(2.1) Maintenance of Appearance

(2.1.1) *Specular Specimens*

Some deterioration in the appearance of the specular flats occurred at most test stations during the period of exposure. It was noticed early in the test that a slight " bloom " had appeared on the samples exposed at Wembley and this was found to be typical of all the samples at the outdoor urban and industrial stations when these were inspected at the end of the first period of the test. The degree of bloom corresponded roughly with the sulphur dioxide concentration at the various stations and increased with time of exposure. Ordinary cleaning methods failed to remove it, but when very hard rubbing pressure was applied the bloom could be reduced. This introduced a variable which it was difficult to control, but as far as possible the same degree of cleaning was applied to all specimens. While it avoided extreme polishing it was considerably better than the cleaning which reflectors generally receive in service. In addition to this general surface effect, pitting had set in on most of the samples from these stations at the end of the test. While the degree of surface bloom appeared to be greater on the specimens with thick films, the degree of pitting was considerably less on the AS series than on the corresponding thin film specimens. For specimens having the same initial anodic film thickness the pitting attack at the urban and industrial outdoor stations corresponded approximately with the degree of bloom and with the time of exposure. At the end of the test some of the samples showed interference colours,

suggesting that the anodic coating had been reduced to an extremely thin film by the weathering attack.

The specimens from the outdoor marine stations differed in one particular from those exposed at inland test sites. Although pitting had set in at the end of the second period and two of the flats from Blackpool showed interference colours, there was less bloom over the surfaces than might be expected from the sulphur dioxide concentrations.

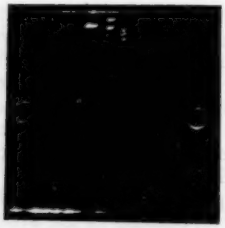
Considerably more variation in behaviour was found in the specimens from the indoor stations than in those from outdoor sites.

In general there was little change in appearance in any of the specimens from the "Light Industrial" group of sites except for those exposed at Test Stations 7 and 10. At the former station a medium degree of matting had taken place, different in character from the surface bloom previously referred to, and giving an appearance of a lightly etched surface. No explanation of this peculiar attack in terms of the corrosive agents known to be present can be given. At Station 10 local attack had developed which was probably caused by the fumes from the tinning bath below the batten.

At the "Heavy Industrial" sites attack was either very heavy as at Stations 13, 15, and 17, or almost non-existent as at 14 and 16. The determining factor appeared to be the presence or absence of condensation, the concentration of corrosive agents being high at all of these test stations. As at the outdoor sites the type of attack varied with the nature of the predominant corrosive agent. All of the stations were very dirty and any pronounced surface attack was accompanied by heavy pitting, but at Station 17, where the main corrosive medium was hydrochloric acid in contrast to the sulphur dioxide of the other stations, there was less bloom than at the other test sites where attack had taken place. That a general surface attack was none the less in progress here was evidenced by the brilliant interference colours shown by the specimens after three months' exposure. At the end of the test the anodic coating had been completely removed from the samples of the BS and CS series at this station and very heavy pitting of the surface had taken place. At Station 13 the attack was so general and so severe that the anodic film was completely removed during the first exposure period and the test was discontinued.

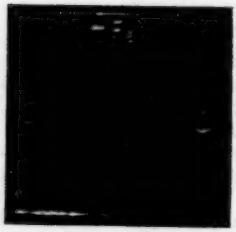
As might be expected the greatest variation in performance was among the specimens exposed at the "Special Industrial" group of test stations, each station having a characteristic and rather special predominating corrosive agent. Even here, however, the general principle held good that there was little evidence of attack except where condensation occurred. At Station 18 the combination of moisture, high sulphur dioxide concentration and considerable solid pollution resulted in a heavy general attack with much pitting. Corrosion troubles experienced in dye works suggested that the samples from Station 19 would be attacked, but the actual deterioration was small. In contrast to this the anodic coatings on the samples from the nitric acid pump house at Station 20 were completely worn away at the end of the first test period and the surfaces were matted. There was, however, no pitting. Mild attack with slight pitting had taken place at Station 21, but the samples from the ammonia plant at Station 22 were unattacked at the end of the first period. These samples were later lost in transport. The combination of moisture, ammonia, and hydrochloric acid at Station 23 produced a fairly uniform attack which gave a matted appearance to the surfaces. Pitting was developing at the end of the test.

Fig. 6 shows photographs of a selection of the specular flats after exposure, together with a control

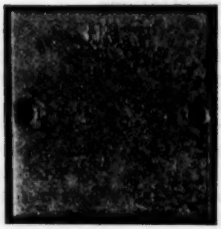


Control specimen.

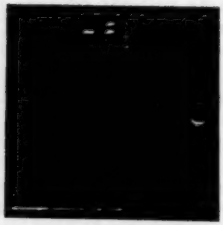
Test station 2 (204 days' exposure).



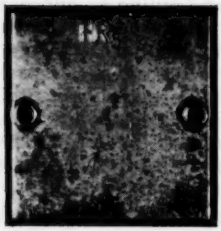
Test station 9 (204 days' exposure).



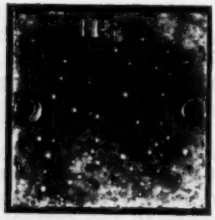
Test station 17 (204 days' exposure).



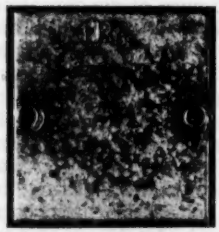
Test station 14 (209 days' exposure).



Test station 13 (204 days' exposure).



Test station 18 (85 days' exposure).



Test station 18 (201 days' exposure).

Fig. 6. Photographs of specular flats (series B5) after exposure.

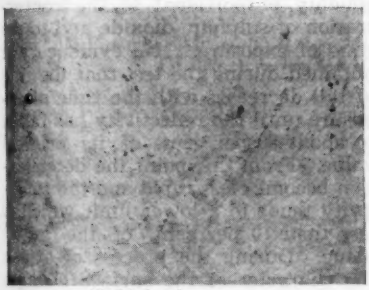
sample photographed under the same conditions.

In order to investigate the nature of the surface bloom characteristic of the appearance of many specimens after exposure, the specular flats were examined microscopically at a magnification of x 50. The areas showing bloom gave the impression that the anodic surface was eroding, the appearance being that of a cracked or "crazed" surface, this crazing being especially marked in the areas surrounding pits. Except on heavily attacked surfaces the attack appeared to be discrete and to be built up from a great number of small areas of erosion, suggesting that even the so-called "general" attack starts at local centres where solid particles have been deposited.

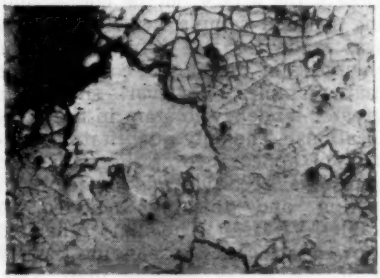
The photographs of Figs. 7a-b show the appearance of typical eroded surfaces at high magnification after 3 and 6 months' exposure.

Data on the degree of pitting and numerical assessment of the appearance of the specular flats in terms of the diffuse reflectivity are included in Tables VI-IX. The results generally confirm the impressions given by visual inspection, but it seems that the diffuse reflectivity may depend on the nature of the surface attack as well as on its extent.

It was interesting to compare the appearance of the specular reflectors with the appearance of the corresponding specular flats. The combination of heat and increased protection from rain reduced the degree of attack on the reflectors relative to that on the flats, but in general they followed the same trends. Comparison

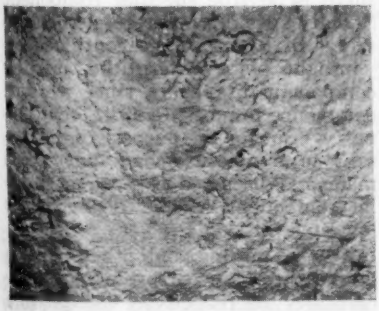


(i) 80 days' exposure.

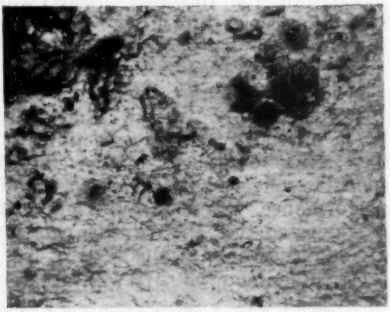


(ii) 205 days' exposure.

Fig. 7a. Photomicrographs of specular flat after exposure at test station 1 *(500 magnifications).*



(i) 92 days' exposure.



(ii) 204 days' exposure.

Fig. 7b. Photomicrographs of specular flat after exposure at test station 2 *(500 magnifications).*

of the heated and unheated reflectors at Wembley showed that the heating had reduced the degree of surface bloom considerably, and it is probable that in service the degree of attack at any of the given locations would not be worse than that shown by the flats in the present tests.

(2.1.2) *Matt Specimens*

The surface texture of the matt flats made observation of surface attack more difficult than with the specular specimens. It was not possible to detect the formation of a light bloom, although when the surface attack had progressed it showed as a difference in the degree of matting of the surface. Such deterioration in appearance was rarely important, however. The progress of both surface and pitting attack on the samples at the different test stations appeared to follow closely the attack on the corresponding specular samples when allowance was made for the difference in the thickness of the anodic coating. The matt samples, however, showed a greater tendency to stain in the dirty locations. The only quantitative measure of appearance of the matt flats which was recorded was the degree of pitting and this is included in Tables VI.-IX. The matt reflectors showed attack corresponding closely with the attack on the matt flats, though of reduced intensity. The staining noted for the flats was even more evident on the reflectors and was sometimes very difficult to remove by the standard cleaning procedure.

(2.2) MAINTENANCE OF PERFORMANCE

(2.2.1) *Specular Specimens*

Tables VI.-IX. record the ratio R′/R of the specular reflectivity of flats after exposure, to the initial specular reflectivity. As a measure of performance, based on experience, it is suggested that the results can be divided into three groups:—

(1) "Satisfactory": R′/R greater than 0.9;

(2) "Doubtful": R′/R between 0.75 and 0.9;

(3) "Unsatisfactory": R′/R less than 0.75.

Generally speaking the reflectivities show changes which correspond to the changes in appearance. When discrepancies occur they are probably due to a pecular type of surface attack.

Neglecting the test sites where a special corrosive agent is responsible for the attack (for example, nitric acid at Station 20), two factors account for the fall in reflectivity: (1) The formation of bloom due to general surface attack, and (2) heavy pitting. Except at those stations where the results are complicated by the presence of chlorides, the first factor is usually responsible, since heavy pitting does not set in until the reflectivity has already been reduced to a low value by the surface attack. The fall in reflectivity at the outdoor stations is roughly proportional to the concentration of sulphur dioxide and to the time of exposure. No evidence was obtained during the test that the rate of fall decreases with the time of exposure until the reflectivity has fallen to about 30 per cent. of its original value. From this point the deterioration becomes less rapid and the reflectivity tends to a lower limit which is less than 10 per cent. of the initial value. During the process of attack the character of the surface changes from an almost purely specular reflector to a preferential reflector in which there is no true specular component. Strictly speaking, therefore, measurements of R′ cannot be continued beyond the point where the specular component disappears, since we then commence to measure a different property. But for the purpose of the present tests measurements have been made and discussed as though a specular component existed down to the lowest levels.

At the marine and other stations where the main corrosive agents are chlorides the reflectivity changes in a different manner. Although a heavy general attack may be taking place, as

happened at Station 17, the reflectivity remains comparatively high until the anodic film collapses when heavy pitting sets in and the reflectivity falls sharply to a low value. It would appear that where there is a high concentration of both chlorides and sulphur dioxide, as at Blackpool, the effect of the chlorides neutralises or over-rides the effects of the sulphur dioxide, since the fall in reflectivity of the samples from this station was considerably less than that expected from knowledge of the sulphur dioxide concentration. This chloride type of attack suggests that the reflectivity is an insufficient measure of performance in service and should be linked with pitting attack now that Champion's scale provides a measure of this quantity.

The tables show that the behaviour

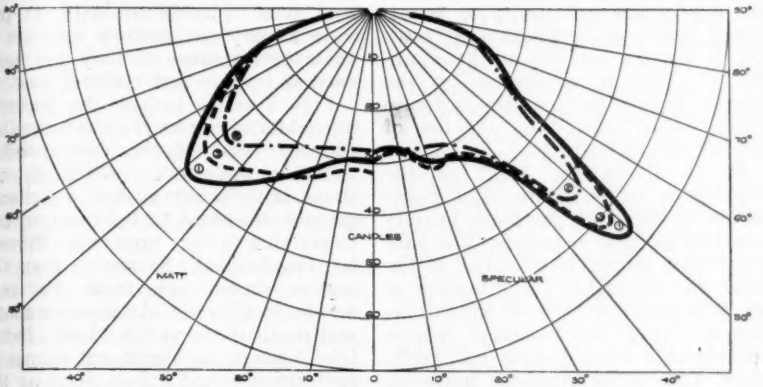


Fig. 8. Light distribution of typical specular and matt anodised aluminium reflectors after exposure.
(1) Control reflectors. (2) Reflectors from test station 15 (204 days' exposure).
(3) Reflectors from test station 23 (208 days' exposure).

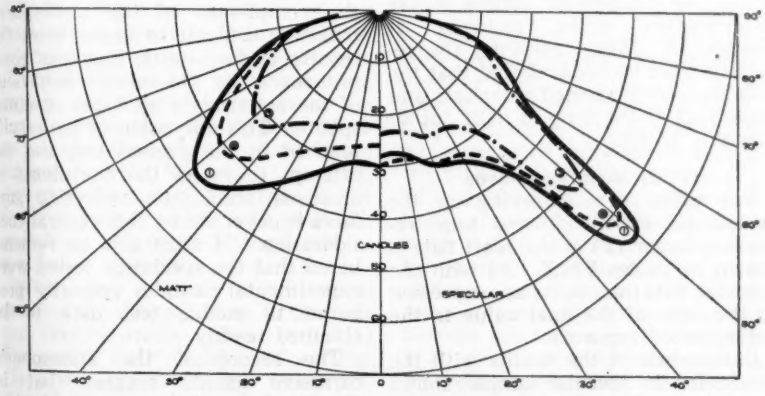


Fig. 9. Light distribution of specular and matt anodised aluminium reflectors during exposure at test station 18.
(1) Before exposure. (2) 85 days' exposure. (3) 201 days' exposure.

of the samples tested was not satisfactory where wetting or condensation took place.

Since the drop in reflectivity is apparently due to erosion of the top surface of the anodic coating we should not expect the reflectivity to be affected either by the thickness of coating or by the quality of the aluminium. This is confirmed by the figures. Only when the drop is due to pitting is it reduced by the use of thicker anodic coatings.

Fig. 8 shows the effect of the weathering attack on the light distribution of some of the more heavily attacked specular reflectors. The bare lamp flux, which is included in the polar curves, makes the influence of the attack on the form of the curves comparatively small except where considerable deterioration has taken place. The curves are useful, however, for showing not only the order of drop in output experienced in the worst cases, but also the effect of bloom on the shape of the curves. Fig. 9 illustrates the progressive nature of the deterioration which occurred at Station 18. When assessing the results it must be remembered that the reflectors were stained after test and some part of the drop in light output was due to this.

(2.2.2) *Matt Specimens*

The effect of weathering on the specific reflectivity (S) and total reflection factor (T) of the matt flats is shown in Tables VI-IX. As with the specular flats the results are expressed as the ratio of the final value to the value before exposure.

Comparison of the results with the results for the specular samples shows a rough correspondence in behaviour of the specimens from the same station. This correspondence, however, ceases to hold when the values of R′/R for the specular samples fall below 0.5-0.6. Whereas R′/R continues to fall with increasing attack to levels below 0.1, S′/S seldom drops below 0.5 and T′/T below 0.7. This difference in the criteria of performance is a function of the property being measured relative to the nature of the surface, and suggests that measurements of the total reflection factor of preferentially reflecting surfaces such as "matt" aluminium will not provide a very satisfactory measure of their performance if they are being used to control and redirect flux.

Figs. 8 and 9 include the performance data of the matt reflectors in addition to that of the corresponding specular reflectors. Although the shape of these curves does not change greatly, the drop in light output due to staining is very apparent. It must be emphasised, however, that the curves shown are those for very severe locations. At many stations, and particularly at the "Light Industrial" group, no significant change in performance had taken place at the end of the test.

(3) DISCUSSION OF RESULTS

As indicated in the introduction, the complexity of the atmosphere makes it difficult to argue from the results of field tests, however comprehensive, to the service behaviour of the material in all types of atmosphere. This discussion of the results reached in the present test and the attempt to assess the usefulness of anodised aluminium reflecting surfaces is governed by this general consideration. It must also be remembered that the specimens tested were experimental samples specially prepared to enable test data to be obtained readily.

The records of the atmospheric corrosive agents suggest that in general the conditions during the test periods were rather less severe than the average conditions which would be met with during a normal service life in the same locations. With regard to the relation of the atmospheric conditions at the outdoor test stations to the average conditions throughout the country, it would

seem that the stations covered a large part of the ranges of rainfall and sulphur dioxide and solid pollutions which occur in this country. A possible exception is the industrial part of Lancashire, where we might expect sulphur dioxide and solid pollution contents comparable to those at Oldbury and Croydon, together with considerably heavier rainfall.

Conditions at indoor locations are much more variable, and the test results can only be taken as indications of the material's behaviour under certain frequently occurring conditions.

One outcome of the present work has been the realisation of the need for a close and detailed investigation of the mechanism by which anodic films are attacked in different types of atmosphere. A very general approach has been made to this problem in these tests, but the tentative conclusions reached need to be confirmed by further investigations.

At least three components of the atmosphere appear to be involved in determining the nature and progress of weathering attack on an anodised surface, but from the results of the tests it seems that measurable attack only takes place when wetting of the surface occurs. We may, therefore, regard wetting of the surface as the decisive factor which will limit the usefulness of anodised aluminium as a reflector material.

When this primary condition is satisfied the major factors in the type and rate of attack appear to be (1) The nature and frequency of wetting; (2) The composition and concentration of the corrosive agents; (3) The type and quantity of solid pollution in the atmosphere. In addition, it is probable that the relative humidity is also a controlling factor, but no positive evidence has been obtained of this.

All atmospheres contain some solid impurities, and microscopical examination suggests that the weathering attack is concentrated around discrete solid particles deposited on the reflector surface. In clean districts the solid deposits are usually in the nature of a fine dust, and this results in a fairly evenly distributed intensity of attack which gives a microscopic appearance of a relatively uniform "bloom." Where larger particles are also in suspension in the atmosphere, as in heavily industrialised districts, a differential attack seems to occur. In addition to the attack originating from the small particle centres, attack proceeds in the areas surrounding the large particles at a greater rate than the general attack, giving rise to pitting superimposed on the general surface erosion. The relation between the general attack and the pitting attack would thus appear to be a function of the type and size of solid particles deposited on the surface. It is known that aluminium oxide is dissolved by sulphurous, sulphuric and other acids and the tests have shown that the concentration of such acids occurring in the atmosphere is sufficient to cause marked deterioration of reflector surfaces similar to those of the test specimens in six months where wetting takes place. The degree of attack increases with increase in both concentration of corrosive media and with time of exposure, other factors being constant. Where sulphur dioxide is the main corrosive agent and the surface is wetted as at outdoor stations the fall in reflectivity is roughly proportional to the sulphur dioxide concentration if the wetting is approximately the same. There is no evidence that the rate of attack decreases with time of exposure until the attack has proceeded so far that the character of the reflecting surface has completely changed.

The presence of bloom in sulphurous atmospheres and its comparative absence in chloride atmospheres (even where the presence of interference colours proves that considerable

erosion of the film has taken place) may be accounted for by the difference in the weathering products formed by the different corrosive agents.

The discussion, so far, has dealt with the action of sulphurous and chloride atmospheres on the anodic coatings, and it can be expected that these will cover most of the atmospheres in which lighting fittings work. In some industrial interiors, however, the action of other gases or fumes associated with factory processes may override the action of the general corrosive agents, and each location must be considered in the light of the corrosive agents present. There has been no evidence, however, that attack will take place unless the surface is wetted either by the fumes or by condensation.

The attack at all test stations where wetting of the surface took place with some regularity was sufficient to reduce the reflectivity of almost all of the specular samples to below 0.9 of their initial value after six months' exposure. The specific reflectivity of the matt samples suffered a corresponding decrease. In addition pitting had set in at many of the locations. The thickness of the anodic coating delayed the onset of pitting, but did not affect the fall in reflectivity, which confirms the suggestion that this is due to a purely surface effect. Neither did the purity of metal have any apparent influence on the performance, although the anodic coating on the Grade A metal is more homogeneous than that on the less pure metals.

Further work needs to be done on both the dirt adhesion properties and the cleaning of the material. Experience during the test suggests that dirt tends to adhere to anodised surfaces more tenaciously than to surfaces of vitreous enamel or glass. On account of the importance of maintenance this tendency to stain is a serious limitation of the material for lighting work. It may be that some more effective cleaner than soap and water will be developed; these materials were too slow in action to be of value under service conditions.

This review of the results of the tests enables present boundaries of usefulness of the material to be laid down. In common with almost all other reflector surfaces anodised aluminium will only function satisfactorily in certain types of atmosphere. At present it can be regarded as satisfactory (in terms of service life) in dry atmospheres, i.e., locations where the surface is never, or only very infrequently, wetted. Provided that this condition is satisfied the present tests indicate that the material will satisfy service requirements. This means that there is, even at present, a wide field of usefulness for reflectors constructed from it. It should function satisfactorily in fittings designed for use in many industries of the lighter kind, in school and office lighting, in shop window and store lighting, and in enclosed units used out of doors, such as floodlights.

Recommendations can be made regarding the thickness of the anodic film. It must be remembered that this film thickness affects the reflectivity of the material as well as the weathering resistance. Where Grade B aluminum is used as a specular material an anodic film thickness of 0.0003 in. is recommended as offering the optimum combination of reflectivity and protection. If superpurity metal is used the film thickness may be increased to 0.0005 in. without markedly affecting the value of the specular reflectivity, while giving greater tolerance in treatment and increased resistance against pitting. A similar film thickness can be used for preferentially reflecting surfaces where the appearance is not affected by the film.

The conclusions drawn from the tests strictly apply only to samples prepared by the particular processes

described. Earlier tests and examination of reflectors returned from service which were prepared by another process indicate, however, that it is unlikely that such materials would show an improvement over those tested.

From the information derived from the tests, further experimental work has been carried out to improve the performance of the material and to extend its usefulness to the illuminating engineer. The problem of sealing has been carefully studied and the performance of thick film samples investigated. Preliminary tests indicate that these later methods of protection will give improved results, and full-scale field tests on a statistical basis are being planned.

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With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—" Trans. Illum. Eng. Soc. (London)."

TABLE VI

Appearance and Performance Data of Flats at Outdoor Test Stations

Test Station Number	Exposure Period (Days)	Relative Sulphur Dioxide Content	Rainfall (Ins./30 days)	Specular Specimens				Matt Specimens			
				Specimen Series	$R'/_R$	Diffuse Reflectivity	Pitting (Champion Scale)	Specimen Series	$S'/_S$	$T'/_T$	Pitting (Champion Scale)
1	205	9.5	1.5	AS	0.86	13.7%	1	CM	0.77	0.85	Nil
				BS	0.81	—	—	DM	0.71	0.81	2
				CS	0.92	2.0%	2	DM	0.81	0.76	Nil
2	204	20.6	1.7	AS	0.33	12.0%	4	CM	0.75	0.81	1
				BS	0.35	6.4%	4–5	DM	0.63	0.76	3
				CS	0.52	3.6%	4	DM	0.59	0.71	2
3	203	19.3	1.4	AS	0.43	16.6%	1	CM	0.64	0.76	1
				BS	0.67	3.5%	3	DM	0.68	0.79	3
				CS	0.59	4.9%	3	DM	0.70	0.77	1
4	199	8.4	5.0	AS	0.94	0.9%	Nil	CM	0.87	0.81	Nil
				BS	0.87	0.9%	2	DM	0.77	0.79	,,
				CS	0.88	1.1%	2	DM	0.75	0.76	,,
5	201	15.9	3.2	AS	0.84	4.7%	4–5	CM	—	0.71	5
				BS	0.90	1.2%	3	DM	0.80	0.79	2
				CS	0.95	1.0%	3	DM	0.76	0.79	3
6	200	4.6	2.6	AS	0.96	1.9%	Nil	CM	0.66	0.86	4
				BS	0.93	0.5%	2	DM	0.65	0.84	1–2
				CS	0.91	1.0%	—	DM	0.66	0.93	1–2

TABLE VII

Appearance and Performance Data of Flats at "Light Industrial" Test Stations

Test Station Number	Exposure Period (Days)	Relative Sulphur Dioxide Content	Specular Specimens				Matt Specimens			
			Specimen Series	$R'/_R$	Diffuse Reflectivity	Pitting (Champion Scale)	Specimen Series	$S'/_S$	$T'/_T$	Pitting (Champion Scale)
7	201	8.3	AS	0.67	5.3%	1	CM	0.81	0.87	Nil
			BS	0.83	1.3%	—	DM	0.80	0.84	,,
			CS	0.79	2.0%	2–3	DM	0.84	0.87	,,
8	204	2.2	AS	0.98	2.0%	Nil	CM	0.74	0.96	Nil
			BS	0.97	0.4%	,,	DM	0.92	0.92	,,
			CS	1.00	1.0%	,,	DM	0.96	0.92	,,
9	204	1.2	AS	0.96	1.7%	Nil	CM	0.99	0.90	Nil
			BS	0.97	0.5%	,,	DM	0.95	0.88	,,
			CS	0.96	0.9%	,,	DM	0.98	—	,,
10	195	1.5	AS	0.81	3.6%	Nil	CM	0.82	0.86	Nil
			BS	0.96	1.0%	2	DM	0.97	0.91	,,
			CS	0.98	0.7%	3	DM	0.89	0.92	,,
11	138	4.7	CS	0.98	1.8%	Nil	No matt samples exposed			
			CS	0.98	1.3%	Nil				
12	107	1.5	AS	1.00	2.2%	Nil	CM	0.90	0.96	Nil
			BS	1.00	0.5%	,,	DM	1.00	0.89	,,
			CS	1.00	0.8%	,,	DM	0.92	0.89	,,

TABLE VIII

Appearance and Performance Data of Flats at "Heavy Industrial" Test Stations.

Test Station Number	Exposure Period (Days)	Relative Sulphur Dioxide Content	Specular Specimens				Matt Specimens			
			Specimen Series	$R'/_R$	Diffuse Reflectivity	Pitting (Champion Scale)	Specimen Series	$S'/_S$	$T'/_T$	Pitting (Champion Scale)
13	85	24.7	AS	0.67	10.5%	1	CM	0.16	0.69	5
			BS	0.06	40.1%	3	DM	0.66	0.79	3–4
			CS	0.01	47.0%	2–3	DM	0.70	0.78	3
14	209	10.9	AS	0.97	0.6%	Nil	CM	0.98	1.00	Nil
			BS	0.95	0.6%	,,	DM	0.90	0.92	,,
			CS	0.93	0.8%	,,	DM	0.94	0.92	,,
15	204	39.3	AS	0.49	3.4%	4	CM	0.50	0.73	Nil
			BS	0.62	2.4%	5	DM	0.63	0.75	1
			CS	0.59	2.4%	6	DM	0.63	0.47	1
16	204	13.0	AS	0.99	1.2%	Nil	CM	0.87	0.84	Nil
			BS	0.96	0.5%	1	DM	0.84	0.74	1
			CS	0.98	1.0%	Nil	DM	0.92	0.82	1
17	204	19.2	AS	0.81	1.6%	5	CM	0.64	0.74	3–4
			BS	0.15	23.9%	—	DM	0.67	0.69	5
			CS	0.17	17.9%	6–7	DM	0.71	0.67	5

TABLE IX

Appearance and Performance Data of Flats at "Special Industrial" Test Stations.

Test Station Number	Exposure Period (Days)	Relative Sulphur Dioxide Content	Specular Specimens				Matt Specimens			
			Specimen Series	R'/R	Diffuse Reflectivity	Pitting (Champion Scale)	Specimen Series	S'/S	T'/T	Pitting (Champion Scale)
18	201	21.9	AS	0.23	27.4%	3	CM	0.65	0.91	3
			BS	0.15	—	4–5	DM	0.73	0.76	3
			CS	0.16	18.8%	4–5	DM	0.71	0.76	3
19	200	3.7	AS	0.99	0.8%	Nil	CM	—	—	—
			BS	0.97	0.8%	2	DM	—	—	—
			CS	0.97	1.3%	1	DM	—	—	—
20	97	5.6	AS	0.02	52.5%	Nil	CM	0.92	0.98	Nil
			BS	0.29	28.2%	,,	DM	1.00	0.96	,,
			CS	0.24	20.2%	,,	DM	1.00	0.88	,,
21	187	11.3	AS	0.97	0.7%	Nil	CM	0.16	0.72	6
			BS	0.91	1.1%	1	DM	0.68	0.74	4
			CS	0.93	1.2%	4	DM	0.66	0.72	3
22	69	3.2	AS	0.98	—	Nil	CM	0.96	—	3
			BS	0.96	—	,,	DM	1.00	—	Nil
			CS	0.98	—	,,	DM	0.97	—	,,
23	208	5.3	AS	0.91	1.2%	1	CM	0.84	0.86	Nil
			BS	0.91	1.7%	1	DM	0.77	0.83	3
			CS	0.81	3.8%	4	DM	—	—	—

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